

We Claim:

- Sub A2
1. A communication receiver, comprising:
an input receiving a modulated analog signal containing digital information;
- 5 a front end unit operable for performing analog to digital conversion, for performing demodulation and for performing timing control, and further operable for producing a demodulated complex-valued digital signal from the modulated analog signal;
- a digital equalizer connected for receiving the demodulated complex
- 10 valued digital signal, comprising:
a first filter operable receiving the demodulated complex valued digital signal;
- a second filter connected to the first filter and operable for reducing the amount of noise and inter symbol interference in the
- 15 demodulated complex valued digital signal; and
a symbol-to bit converter connected to the second filter.
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2. The communication receiver according to claim 1 wherein the first filter operates to reduce the eigenvalue spread of an input spectrum of the
- 20 demodulated complex valued digital signal.
3. The communication receiver according to claim 1 wherein the second filter is further operable for reducing the amount of noise and inter symbol interference of the demodulated complex valued digital signal without training
- 25 data.
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4. The communication receiver according to claim 1 wherein the second filter further includes a rotator for restoring the phase of the demodulated complex valued digital signal without the use of training data.

5. The communication receiver according to claim 1 wherein the second filter further includes a nonlinear feedback network for removing the inter-symbol interference without the use of training data in the demodulated complex valued digital signal.

6. The communication receiver according to claim 1 wherein the first filter further comprises an L-tap Finite-Impulse-Response (FIR) Filter, where $L \geq 1$, whose first tap is set to a fixed value, and the filter's taps are adjusted so that its output power is minimized.

7. The communication receiver according to claim 1 wherein the second filter further comprises an M-tap FIR filter whose taps are adjusted according to the following formula:

$$c_{n+1}[m] = c_n[m] + \varphi_n(s_s[n]) s_s^*[n-m] \quad m = 1 \dots M$$

where $c_n[m]$ is the m-th tap of the second filter after calculation of n outputs, $s_s[n]$ is the input sequence to the second filter, $s_s[n]$ is the sum of the output of the second filter and a decision feedback filter, and $\varphi_n(\bullet)$ is a complex valued function, whose parameters may depend on the symbol index n.

and the decision feedback filter is an N-tap backward FIR-filter whose taps are adjusted according to the following formula:

$$d_{n+1}[i] = d_n[i] + \Psi_n(s_s[n]) \hat{a}^*[n-i] \quad i = 1 \dots N$$

where $d_n[i]$ is the i-th tap of the decision feedback filter after calculation of n outputs, $\hat{a}[n]$ is a sequence of detected data, and $\Psi_n(\bullet)$ is a complex valued function, whose parameters may depend on the symbol index n.

8. The communication receiver according to claim 7, wherein for some values of n:

$$\varphi_n(x) = \delta[n] (\operatorname{Re}^2(x) - k_2) \operatorname{Re}(x)$$

where $\operatorname{Re}(-)$ denotes the real part of a complex number, k_2 is a scalar, and $\delta[n]$ $n = 1, 2, \dots$ is a sequence of numbers.

9. The communication receiver according to claim 7, where for some values
5 of n :

$$\varphi_n(x) = \delta[n] (|x|^2 - k) (x)$$

where k is a scalar, and $\delta[n]$ is a sequence of numbers.

10. The communication receiver according to claim 7, where some values
of n :

$$\varphi_n(x) = \delta[n] (x - \hat{a}(x))$$

- 10 where $\hat{a}(x)$ is the result of a memoryless nearest neighbor symbol detector whose
input is x , and $\delta[n]$ is a sequence of numbers.

11. The communication receiver according to claim 7, where some values
of n :

$$\Psi_n(x) = \delta[n] (\operatorname{Re}^2(x) - k) \operatorname{Re}(x)$$

- 15 where k is a scalar, and $\delta[n] = 1, 2, \dots$ is a sequence of numbers.

12. The communication receiver according to claim 7, where for some values
of n :

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$$\Psi_n(x) = \delta[n] (|x|^2 - k)(x)$$

where k is a scalar, and $\delta[n]$ is a sequence of numbers.

13. The communication receiver according to claim 7, where some values of n :

$$\Psi_n(x) = \delta[n] (x - \hat{a}(x))$$

5 where $\hat{a}(x)$ is the result of a memoryless nearest neighbor symbol detector whose input is x , and $\delta[n]$ is a sequence of numbers.

14. The communication receiver according to claim 1, wherein the second filter further comprises:

10 an adaptive rotator connected to receive the demodulated complex valued digital signal;

an adaptive feed forward equalizer finite impulse response filter connected to the adaptive rotator;

15 a signal summation circuit connected to the adaptive feed forward equalizer finite impulse response filter and to an adaptive finite impulse response filter, the output of which is connected to update the adaptive rotator, the an adaptive feed forward equalizer finite impulse response filter and the adaptive finite impulse response filter;

20 a symbol detector connected to the signal summation circuit and the symbol-to-bit convertor; and

the adaptive finite impulse response filter connected to the symbol detector and operable for adapting to the summation result of the signal summation circuit.

15. The communication receiver according to claim 1, wherein the modulated analog signal is a modulation type selected from the group consisting of PAM (Pulse Amplitude Modulation), QAM (Quadrature Amplitude Modulation), PSK (Phase Shift Keying), CAP (Carrierless AM-PM), NRZ (Non-Return to Zero), offset-QPSK, and $\pi/4$ -QPSK.

- Sub AB 7 16. A digital communication receiver, comprising:
- a input stage receiving an analog signal containing digital information;
 - an analog to digital converter connected for producing a complex-valued digital signal from the modulated analog signal;
 - a demodulator connected for producing a demodulated complex-valued digital signal from the complex-valued digital signal;
 - a pre-equalizer filter connected to receive the demodulated complex-valued digital signal, comprising:
 - 15 a first adaptive finite response filter having an output, having a tap adjustment input and connected to receive the demodulated complex-valued digital signal;
 - a first summation circuit connected to sum the demodulated complex-valued digital signal with the output of the first adaptive finite response filter to produce a pre-equalized complex-valued signal;
 - 20 a function circuit connected to receive the pre-equalized complex-valued signal and operable for producing therefrom a non-linear response to the pre-equalized complex-valued signal;
 - an adaptation unit connected to receive the demodulated complex-valued digital signal, connected for receiving the non-linear response and connected to the tap adjustment input of the adaptive finite response filter to provide an adjustment to the first adaptive finite response filter;
 - 25 a digital decision feedback equalizer connected to receive the pre-equalized complex-valued signal, comprising:
 - 30 a rotator having an adaptive input and connected to receive the pre-equalized complex-valued signal and operable for restoring the phase

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of input data contained in the pre-equalized complex-valued signal without the use of training data;

a feed forward equalizer finite input response filter having an adaptive input, an input connected to the rotator, an output, and operable for adaptively reducing the amount of noise and inter-symbol interference in the pre-equalized complex-valued signal;

a second summation circuit connected to sum the output of the feed forward equalizer finite input response filter with the output of a second adaptive finite response filter and for producing therefrom a corrected complex-valued signal;

a symbol detector connected to receive the corrected complex valued signal and to produce a symbol signal;

the second adaptive finite response filter having an output, an adaptive input and connected to receive the symbol signal;

wherein the corrected complex-valued signal is connected to the adaptive input of the rotator, the adaptive input of the feed forward equalizer finite input response filter and the adaptive input of the second adaptive finite response filter; and

a symbol-to-bit converter connected to receive the symbol signal and to produce therefrom digital bits corresponding to the digital information.

17. A method of receiving a digital communication signal in the presence of inter-symbol interference, comprising the steps of:

receiving an analog signal modulated with digital information;

converting the analog signal to produce a digital signal;

multiplying the digital signal with sine and cosine signals to produce a complex-valued digital signal;

adaptively pre-equalizing the complex-valued digital signal to produce a pre-equalized complex-valued digital signal;

adaptively equalizing the pre-equalized complex-valued signal to reduce the inter-symbol interference and to produce a corrected complex valued symbol signal; and

5 converting the corrected complex valued symbol signal to the digital information.

18. The method according to claim 17, wherein the step of adaptively pre-equalizing further comprises the steps of:

10 adaptively filtering the complex-valued digital signal with an adaptive filter to produce a filtered complex-valued digital signal

summing the complex-valued digital signal with the filtered complex-valued digital signal to produce the pre-equalized complex-valued digital signal;

15 producing a non-linear response to the pre-equalized complex-valued signal; and

modifying taps of the adaptive filter in response to the non-linear response to the pre-equalized complex-valued signal and in response to the complex-valued digital signal.

20 19. The method according to claim 17, wherein the step of adaptively equalizing further comprises the steps of:

adaptively rotating the pre-equalized complex-valued signal to produce a rotated complex valued signal;

25 adaptively filtering the rotated complex valued signal to produce a filtered rotated complex valued signal;

summing the filtered rotated complex valued signal with an adapted filter output to produce an adapted complex-valued signal;

detecting the symbols in the adapted complex-valued signal to produce the corrected complex valued symbol signal; and

30 producing the adapted filter output by adaptively filtering the corrected complex valued symbol signal.

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Sub A4 20.

A communication system, comprising:

a digital communications transmitter;

a communications medium; and

a digital communications receiver, comprising:

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a input receiving a modulated analog signal containing digital information;

an analog to digital converter connected for producing a complex-valued digital signal from the modulated analog signal;

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a demodulator connected for producing a demodulated complex valued digital signal from the complex valued digital signal;

a digital equalizer connected for receiving the demodulated complex valued digital signal, comprising:

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a first filter operable receiving the demodulated complex valued digital signal;

a second filter connected to the first filter and operable for reducing the amount of noise and inter symbol interference in the demodulated complex valued digital signal; and

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a symbol-to bit converter connected to the second filter.

Sub B17 21. The communication receiver according to claim 1 wherein the receiver is used with a digital subscriber loop of a telephone network.

25 22. The communication receiver according to claim 1 wherein the receiver is used with a coaxial cable television infrastructure.

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